

WEPP MODEL APPLICATIONS FOR EVALUATIONS OF BEST MANAGEMENT PRACTICES

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Summary

The Water Erosion Prediction Project (WEPP) model is a process-based erosion prediction technology for application to small watersheds and hillslope profiles, under agricultural, forested, rangeland, and other land management conditions. Developed by the United States Department of Agriculture (USDA) over the past 25 years, WEPP simulates many of the physical processes that are important when estimating runoff, soil erosion, and sediment delivery at a location having unique climate, topography, soils, and plants/tillage/management. A variety of user interfaces and databases make the model very easy to apply and use, particularly within the United States. The USDA Agricultural Research Service (ARS) has developed a stand-alone Windows WEPP system, as well as internet web-based hillslope and GIS watershed interfaces. GeoWEPP is an ArcGIS extension for performing model applications with a user's own detailed geospatial topographic, soils, and land management data. The USDA Forest Service (FS) also has a variety of custom online web-based interfaces for WEPP model applications targeted to specific problems, such as forest road design, effects of timber harvest operations, and identification of areas most important for remediation after wildfires. This presentation provides information on the current WEPP model and interfaces, and demonstrates the model's application at a field site. Existing conditions (climate, soils, slope, cropping/management) were used to provide baseline runoff and erosion estimates, and then the impacts of various alternative conservation practices were explored, including modified crop rotations, use of conservation tillage, strip cropping, and buffer strips. For the example in this paper for a 50-m long 6% slope eroding hillslope profile in southern Indiana, use of a system leaving substantial residue and/or vegetative cover on the soil is needed to successfully reduce soil loss below a tolerable level.

Introduction

Soil erosion by wind and water detachment and transport processes continues to be a serious threat to productive soils throughout the world. When raindrops, flowing water, and/or wind removes topsoil, it also detrimentally impacts a number of soil properties. Soil organic matter content, nutrient levels, and water

holding capacity can all decrease. Sediment in water is the largest pollutant of streams and lakes by volume, and deposition of this sediment can clog harbors and waterways – resulting in high dredging costs to maintain navigability. Pollutants transported with sediment and runoff water (nitrogen, phosphorus, pesticides, pathogens) can also cause large off-site water quality problems, including eutrophication and hypoxia.

Farmers and land managers need the ability to estimate soil loss for their current agricultural practices, as well as investigate how the use of alternative land management systems may be able to help them reduce the risk of erosion that can threaten their soil and its productivity. Empirically-based soil erosion prediction technology, such as the Universal Soil Loss Equation (USLE), has been used for many years to estimate the amount of long-term average annual soil loss. However, USLE is limited by its simple equation structure, is difficult to extend beyond the experimental database used in creating the equation subfactors, and cannot predict a variety of other important and related processes, such as runoff, sediment deposition, or sediment delivery.

Over the past 25 years, new generation water erosion prediction technology that is based upon mathematical representation of the important physical processes occurring has been developed by the U.S. Dept. of Agriculture (USDA). The Water Erosion Prediction Project (WEPP) model simulates processes of surface and subsurface hydrology, plant growth, water balance, residue decomposition, soil disturbance and consolidation, interrill and rill detachment, sediment transport, and sediment deposition. In addition to simulation of soil detachment, transport and deposition on hillslope profiles (at a scale of application similar to USLE), WEPP can also be applied to small watersheds composed of multiple hillslope areas connected to channels and impoundments, to allow for field- and farm-scale based analyses, up to areas of about 260 ha in size. Advanced GIS tools are under development to increase this up to 20 km² or more.

Materials and Methods

The WEPP erosion prediction system is composed of a scientific model, coded in the Fortran programming language, some large databases for climate, soils and management, and a variety of user interface programs. WEPP can be applied in either a single storm mode, or in a continuous simulation mode, depending upon the type of user and model application. Climate input to WEPP is typically generated synthetic weather when the model is being applied in a continuous simulation mode to estimate long-term average annual runoff and soil loss rates, as well as conduct probability risk analysis. Observed weather data containing breakpoint precipitation information from recording raingauges can also be used as input.

During a continuous simulation, the scientific model determines the status of the soil water content down through the soil profile layers, and if a rain storm occurs on a day, will estimate infiltration of water into the soil through the event using a Green-Ampt Mein-Laurson procedure adjusted for unsteady rainfall (Flanagan and Nearing, 1995). If rainfall rate exceeds infiltration rate, and all soil surface depressions are filled, then runoff will be predicted to occur. Surface runoff rate is estimated using a solution to the kinematic wave equation, or an approximation to it to obtain the peak runoff rate. Peak runoff rate allows computation of the flow shear stress, which in turn is used in the sediment transport and rill detachment equations. Interrill detachment is a function of

effective rainfall intensity and interrill runoff rate, as well as several other factors, including slope, roughness, particle size, and adjusted interrill erodibility. Rill detachment occurs when flow shear stress exerted on the soil exceeds critical shear stress, and sediment load is below sediment transport capacity. An excess flow shear stress equation is used, with an adjusted rill erodibility multiplied by the difference between the flow shear stress and the adjusted critical shear stress. The change in sediment load down a slope with distance is the sum of the interrill sediment delivery rate to the rills and the rill detachment or deposition rate (Flanagan and Nearing, 1995).

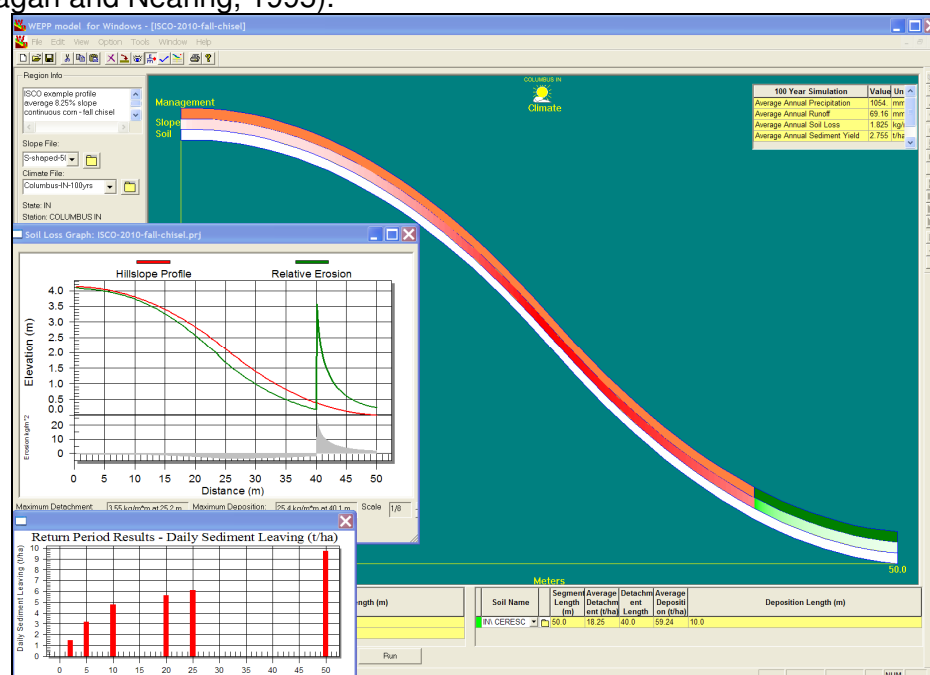


Figure 1. Screen capture of results of a 100-yr WEPP model simulation utilizing the WEPP Windows interface for a complex hillslope profile with a crop on the upper region and a grass buffer on the toe.

The WEPP science model is run from a set of flat ASCII input files (slope, soil, climate, management, irrigation, run information (I/O), watershed structure, channel parameters, impoundment parameters), and generates a set of flat ASCII output files, based upon the values in the input run information file. In hillslope simulations, the main model output file can provide very detailed storm-by-storm information on runoff and soil loss, monthly, annual, or average annual results. Other text output files provide information on soil, plant, and water output, crop yield, winter hydrology, event-by-event runoff and sediment line summaries, and soil and plant parameter information through time. Return period information on rainfall, runoff and sediment loss can be determined from long simulations, and displayed in tabular and graphical form (Figure 1). The Windows interface program facilitates easy creation and modification of model input files and reading/viewing of output files. Graphical viewing of soil loss spatially down a slope profile is available, as is viewing of over 100 model parameters and outputs through time. Simple watershed simulations can also be conducted with this interface, but for more complex applications, use of other programs that access and utilize geospatial topographic, soils, and land-use data are more appropriate. (WEPP url: <http://www.ars.usda.gov/Research/docs.htm?docid=10621>)

GeoWEPP (Renschler, 2003) is a geospatial interface to the WEPP Windows software components. It is available as an ArcView 3.x or ArcGIS 9.x extension, that allows a user to use their own specific digital elevation model (DEM), land-use, and soils information for a location of interest.

More recent model interface work has focused on web-based interfaces, both for simple hillslope simulations as well as more complex watershed erosion assessments. The USDA Forest Service has an extensive set of web-based WEPP interfaces, custom designed to address erosion applications for forest road design, harvesting regions, and areas having experienced wildfires (<http://forest.moscowfs.wsu.edu/fswepp/>). ARS also has several web-based interfaces for applications to cropland situations, and which utilize the existing national databases for the model (<http://milford.nserl.purdue.edu>). One of these interfaces is a prototype web-based WEPP GIS system, that allows a watershed application of the model to any location within the United States and utilizes nationally available USGS topographic DEMs and other information. Figure 2 shows a screen capture of results from a watershed simulation using this interface.

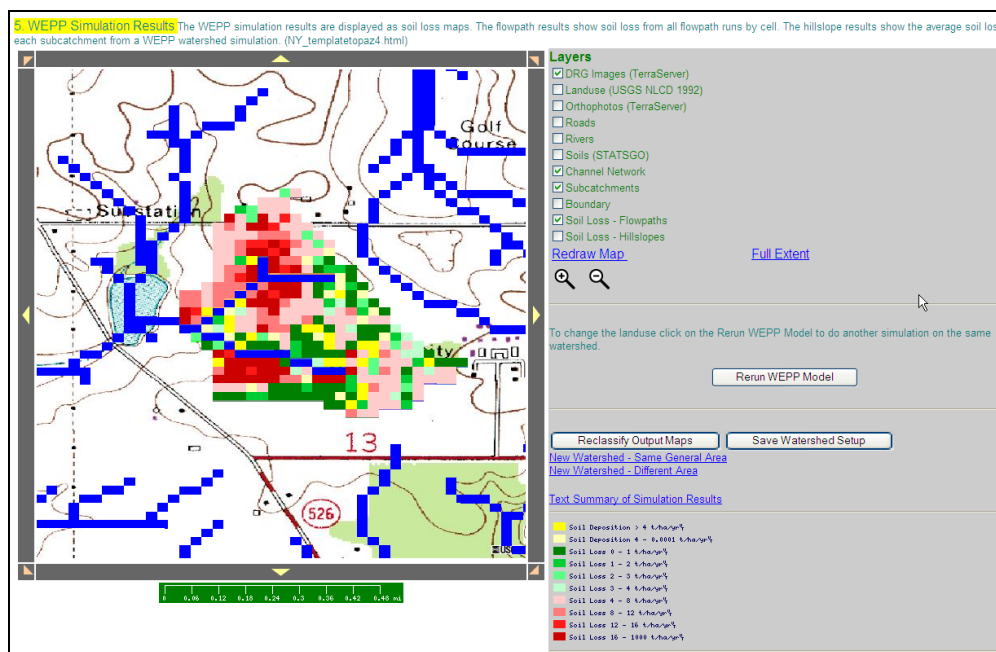


Figure 2. Screen capture of results of a 10-yr WEPP model simulation utilizing the web-based WEPP GIS interface for a small field watershed. Spatial soil loss values are shown in shades of red (above T) and green (below T), and yellow indicates deposition.

For the exercise in this paper, hillslope simulations using the WEPP Windows interface (v2010.1) were conducted for a field site located in south central Indiana, near the city of Columbus. An S-shaped profile (Figure 1) with an average slope of ~6% on a Pekin silt loam soil was simulated, using soil information from the WEPP database and a CLIGEN-generated climate input file for that location. The T-value for the soil is 9 Mg ha⁻¹, and the conventional cropping system is a rotation of corn and soybeans with fall moldboard plowing. Various alternative WEPP model simulations were conducted here.

Results and Discussion

Table 1 shows the results of the WEPP model simulations for this example slope profile. The existing conventional system under fall moldboard plowing has

an extremely high soil loss rate of 51.1 and sediment loss of 47.5 Mg ha⁻¹, which is more than 5 times the tolerable soil loss value (T) of 9 Mg ha⁻¹. Placing a permanent grass buffer strip on the last 10 m of the profile will reduce off-site sediment loss to 11 Mg ha⁻¹, however this is still greater than T, and soil above the buffer is still eroding at an excessive rate. Switching to a continuous corn rotation with a buffer strip will reduce sediment loss rate below T, but again the upslope erosion is still too high. Even switching to a strip-cropping system with five 10-m long strips and a long rotation including alfalfa was not able to reduce the soil loss values enough under either conventional or conservation tillage. Some type of tillage system that leaves high amount of residues (no-till), or a permanent vegetation such as forest, grass or alfalfa are needed to reduce soil erosion to rates below T.

Table 1. WEPP model 100-yr simulation results for example profile.

Cropping/Management System	Average Annual Runoff (mm)	Average Annual Soil Loss* (Mg ha ⁻¹)	Average Annual Sediment Loss (Mg ha ⁻¹)
Fall moldboard plow corn-soybeans rotation	173	51.1**	47.5**
Fall plow corn-soybeans with 10-m grass buffer	146	52.6	11.2
Fall moldboard plow continuous corn	161	28.3	28.0
Fall plow cont. corn with 10-m grass buffer	140	28.8	7.0
Fall chisel plow continuous corn	163	18.7	18.7
Fall chisel cont. corn with 10-m grass buffer	142	18.7	4.8
Fall chisel plow corn-soybeans rotation	177	40.6	37.3
Fall chisel plow corn – no-till soybeans	188	26.0	23.6
Conv. till – corn,soybeans, wheat, alfalfa(4-yr)	168	17.6	16.7
Conv. till – c-s-w-a-a-a-a with 10-m grass buffer	145	18.6	4.5
Strip(5)crop – staggered c-s-w-a-a-a-a –conv.	150	15.2	12.8
Strip(5)crop – staggered c-s-w-a-a-a-a –chisel	147	11.2	9.8
No-till continuous corn	196	2.0	2.0
No-till corn-soybeans rotation	206	4.4	4.4
No-till corn-soy with 2-m grass buffer	191	3.6	2.6
No-till corn-soy with 10-m grass buffer strip	168	4.1	2.2
Continuous alfalfa, replant every 5 years	162	7.4	6.9
Permanent grass vegetation	155	0.8	0.7
Permanent forest vegetation	190	1.0	0.9

* Soil loss on detaching area of profile only (above toe-slope and grass strip).

**Values highlighted in red exceed T. The T-value for this soil (Pekin silt loam) is 9 Mg ha⁻¹.

Conclusions

The WEPP model is a powerful tool that can be used to assess the impacts of various land management practices on runoff, soil loss, and sediment yield. Easy-to-use interfaces and large databases are available for application of the model. For a specific location with unique climate, soil, and slope profile shape, WEPP can help determine what conservation practices and crop rotations will best help conserve soil resources. The exercise in this paper illustrates the variety of management practices that can be evaluated, and in this case, the great importance of maintaining high soil surface cover.

References

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